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AN EXPERIMENTAL STUDY AND PARAMETRIC OPTIMIZATION OF AWJC ON ALUMINIUM 7075 ALLOY

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ABSTRACT

Abrasive waterjet cutting is a non-traditional cutting processes capable of cutting wide range materials. This report assesses the influence of process parameters on surface roughness which is an important cutting performance measure in abrasive waterjet drilling of Aluminium alloy. The process variables considered here include abrasive flow rate, standoff distance, feed rate and water pressure. Experiments were conducted in varying these parameters for drilling of Aluminium alloy using abrasive waterjet cutting process. For selecting the cutting parameters, an empirical model for the prediction of surface roughness in abrasive water jet drilling of Aluminium alloy is developed using regression analysis. This developed model has been verified with the experimental results that reveal a high applicability of the model within the experimental range used.

The better machining capabilities of abrasive waterjet cutting (AWJC) characterized by the absence of thermal distortion make it highly competitive with other cutting processes employing plasma and lasers. The present report was oriented towards examining the effect of AWJC parameters like abrasive flow rate, feed rate, standoff distance and water pressure on the surface roughness produced with Aluminium alloys. Box-behnken design used for conducting the trials, and a combined technique of BBD-based response surface methodology was disclosed for obtaining the optimal level of AWJC parameters. The BBD was supplemented with analysis of variance to identify the vital parameters affecting the quality characteristics. The optimal parameter setting was validated by conducting a confirmation test. The drilled hole surfaces were also examined using field emission scanning electron microscope images.

***KEYWORDS:** Parametric Optimization, Aluminium 7075 alloy & Abrasive Water Jet Cutting*

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Original Article

1. INTRODUCTION

Tsai. F. C., et al [1] (2013) Investigated polishing on SKD 61 mild steel using SIC with wax coating. This paper investigates the abrasive jet polishing of electro-discharged-machined and mild steel specimen was used 2000, 3000 or 8000 Sic particles and the compound additive comprising pure water. The experiment shows that when the polishing process was performed using 2000 Sic particle with a pure water and water was additive it was found that the surface roughness is reduced from Ra=1.0 micrometer to 0.08 micrometer within 10 min of SKD 61 surface polishing the ground SKD 61 surface using 3000 Sic particles with pure water and water wax, the surface roughness is found to reduce from an initial value of Ra=0.36 micrometer to a final value of Ra=0.054 m within 60 min. A gas atomization technique is employed to fabricate wax coated 3000 Sic particle for improving the polishing performance. After the experiment, the result show was that the wax-coated abrasive particle reduces the polishing time and achieves an improved surface finish.

Nagdeve. L., et at [2] (2012) In this paper, Taguchi method is applied to find optimum process parameter for Abrasive waterjet machining(AWJM). Further experimental investigation was conducted to assess the influence of abrasive waterjet machining (AWJM) process parameters on MRR and Surface Roughness (Ra) of aluminum. Also, optimize the AWJM process parameter for effective machining and to predict the optimal choice for each AWJM parameter such as pressure, standoff distance. This paper analysis of the Taguchi method reveals that, in general the standoff distance significantly affects the MRR while, Abrasive flow rate affects the surface Roughness. However, experiments are carried out using (L9) orthogonal array by varying pressure, standoff distance, Abrasive flow rate and Traverse rate respectively.

Nagdeve. L., et al [3] (2012) the paper discusses the use of Taguchi Method to find the optimal process parameters of Abrasive waterjet machining. The aim of the project is to conduct analysis on machine parameter and its impact on MRR and SR of workpiece Al7075. The approach is based on S/N ratio and to predict optimal choice for each AJWM parameters like Abrasive flow rate, standoff distance and Abrasive grit size. The paper further discusses results obtained from ANOVA

Kumar Karna, S., et al [4] (2012) The journal discusses about using of Taguchi method for optimizing the process parameters. Therefore, Off-line quality control is considered to be an effective approach to improve product quality at a relatively low cost. Also, analysis of variance (ANOVA) was used to study the effect of process parameters on the machining process. The approach was based on Taguchi method, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) are employed to study the performance characteristics.

Rama Rao, S., et at [5] (2012the paper discusses various process parameters such as voltage, feed rate and electrolyte concentration on the predominant machining criteria..the metal removal rate (MRR) was studied. The orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA), and regression analyses are employed to find the optimal process parameter levels and to analyze the effect of these parameters on metal removal rate values. The confirmation test with the optimal levels of machining parameters was carried out in order to illustrate the effectiveness of the Taguchi optimization method.

Chatterjee, A., et al [6] (2011) In this paper An effect of inherent characteristics of water jet flaring on the straightness of the through cut has been studied. Also, an attempt has been made to establish the effect of jet traverse speed on the straightness of the cut and surface roughness through experiments for different materials like aluminum, stainless steel, sandstone and marble. This paper also deals with the quantitative taper angle analysis and qualitative roughness analysis for above materials.

Kandpal Chandra, B. et at [7] (2011) In this paper investigated the testing and analyze various process parameters of abrasive jet machining**.** The paper discusses result obtained based on the experiments by changing pressure and tip distances with glass and ceramic plates with different thickness. It was observed that as nozzle tip distance increases, material removal rate (MRR) increases as it is in the general observation in the abrasive jet machining process. As the pressure increases material removal rate (MRR) is also increased as we found in AJM process. Similarly, as abrasive particle size increases MRR increases.

2. PROBLEM STATEMENT

Recently developed materials like ceramics, composites and alloys have huge demand in industries but only a considerable number of researchers had applied scientific approach to improve the quality of cutting characteristics of AJWM

The objectives of the present work are listed below:

- To study the effect of drilling process parameters (Abrasive flow rate, water pressure, stand-off distance and cutting speed) on the performance characteristics (surface roughness) of Abrasive water jet drilling on 7075 Aluminium alloy plate.
- The mathematical/regression models were developed according to Box-behnken design.
- To optimize the abrasive water jet drilling parameters for minimum surface roughness (SR) in drilling of 7075 Aluminium Alloy plate using desirability approach.

3. DESIGN METHODOLOGY

- Preparing CNC Abrasive jet machine for drilling operation.
- Performing trial operation in CNC-Abrasive water jet machine to fix the values of the drilling parameters for the experiments.
- Conducting drilling operation on 7075 Aluminium alloy using different levels of abrasive flow rate, water pressure, stand-off distance and cutting speed.
- Observing and measuring the surface roughness using surface roughness tester

3.1. Experimental Plan

The four input process parameters namely, Abrasive flow rate, water pressure, stand-off distance and feed rate considered. Average surface roughness (Ra) is taken as characteristic to be measured. The Box-behnken design is used. It can accommodate four factors each at three levels. Each row of experimental matrix represents the experiment number which contains the corresponding combination of the process parameters value. Thus a total of twenty-nine experiments are conducted in drilling operation of 7075 Aluminium alloy plate. The experimental factors and their levels are listed in the table 3.1. The experiments were performed according to box-behnken designed experimental matrix are listed in table 3.2.

Table 3.1: Factors and Levels Selected for Cutting Operation of Aluminium Alloy Plate

Factors	Unit	Level 1	Level 2	Level 3
Abrasive flow rate	(g/min)	200	400	600
Water pressure	(bar)	3400	3600	3800
Stand-off distance	(mm)	1	1.5	2
Feed rate	(mm/min)	15	20	350

Table 3.2: Box-behnken designed experimental matrix

Run	Abrasive flow rate g/min	Water pressure Bar	Stand-off distance mm	Feed rate mm/min
1	400	3600	1.5	300
2	600	3600	2	300
3	400	3600	2	350
4	400	3600	2	250
5	400	3600	1	250
6	400	3400	2	300
7	600	3600	1	300
8	400	3600	1	350
9	600	3600	1.5	250
10	200	3400	1.5	300
11	600	3400	1.5	300
12	400	3800	1.5	350
13	200	3600	1	300
14	400	3600	1.5	300
15	400	3800	2	300
16	200	3800	1.5	300
17	200	3600	2	300
18	400	3800	1.5	250
19	400	3400	1	300
20	400	3400	1.5	250
21	400	3600	1.5	300
22	400	3800	1	300
23	200	3600	1.5	250
24	200	3600	1.5	350
25	400	3600	1.5	300
26	400	3600	1.5	300
27	600	3800	1.5	300
28	600	3600	1.5	350
29	400	3400	1.5	350

3.2: Experimental Set Up, Work Materials and Instruments

The photographic view of abrasive water jet cutting machine is shown in Figure 3.1 and the pictorial view of the experimental setup for the present work is shown in Figure 3.2.

3.2.1: Machine and Instruments

The Abrasive water jet drilling of 7075 Aluminium alloy plate was performed by using water jet Germany, Chennai is shown in figure 3.1.

Figure 3.1: Abrasive Water Jet Machine used for Experimentation

Figure 3.2: Pictorial View of Abrasive Water Jet Cutting

3.2.2 Work Piece Material

In the present work, the 7075 Aluminium Alloy plate has been considered as a work material. Which is supplied by Narendra steels, Mumbai. The chemical composition of 7075 Aluminium Alloy is depicted by the following

Energy Dispersive X-ray Spectroscopy (EDS) image 3.3. the physical and chemical properties of workpiece material as shown in table 3.1.and Table 3.2.

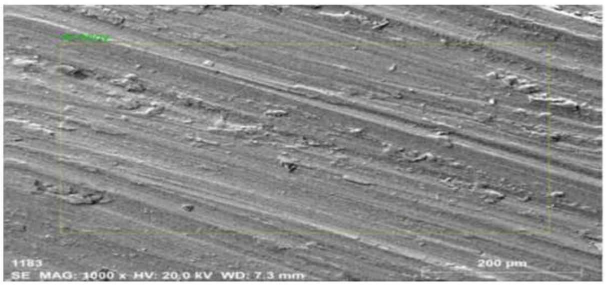

Figure 3.3: EDS Image of 7075 Aluminium Alloy Plate

Table 3.3: Composition of 7075 Al alloy

Component	Wt. %	Component	Wt. %
Al	87.3-90.3	Mn	Max 0.1
Cr	Max 0.04	Si	Max 0.12
Cu	2-2.6	Ti	Max 0.06
Fe	Max 0.15	Zn	5.7-6.7
Mg	1.96-2.6	Others	Max 0.15

3.2.5. Mechanical Properties

Table 3.5: Mechanical Properties of AL Alloy 7075

Property	Typical valve
Hardness, Rockwell C	36
Tensile Strength, Ultimate	496 MPa
Tensile Strength, Yield	434 MPa
Modulus of Elasticity	71.7 GPa
Poisson's Ratio	0.33
Shear Modulus	26.9 GPa
Shear Strength	290 MPa

3.3. Experimental Procedure

For the purpose of the experiment the plate has been drilled with help of input parameter for the drilling process have been fixed with the help of few trials runs. Total of 29 experiments has been performed according to the Box-behnken design. A sample workpiece after cutting operation is shown in Figure 3.4

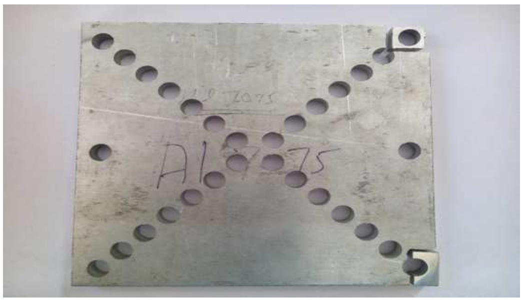

Figure 3.4: Work Piece with Twenty-Nine Drilled Holes

3.4. Measurement of Performance Characteristics

3.4.1. Calculation of Surface Roughness (R_a)

After cutting, surface roughness has been measured for all the 9 slots by using Talysurf which has shown in figure 3.5. Measurements of surface roughness parameters, namely the average surface roughness value (Ra) is made over the cutting surfaces using Taylor Hobson Precision Surtronic 3+

Figure 3.5: Representation of Surface Roughness Measurement

4. RESULTS

In the previous chapter details of the experimental plan, set up and procedure have been discussed. In this chapter results are presented, discussed and analyzed. Analysis has been done for single objective optimization on drilling of 7075 Aluminium alloy plate. Also the, observed data have been analyzed for mathematical modeling, optimization and response surface plots.

4.1.1. Optimization of Surface Roughness (R_a)

For optimization of the process parameters in drilling, desirability approach has been adopted. The Box-behnken tool from design expert software has been used for this purpose. The Experimental results with three repetitions of each experiment as per Box-behnken design are listed in **Table** (**4.2**). The response (Ra) is taken from **Table** (**4.2**).

4.1.2. Analysis of Variance (ANOVA) for Surface Roughness

The statistical technique of analysis of variance (ANOVA) is applied on experimental data given in **Table (3.1**, and **3.2**) to identify the significant machining parameters influencing the output response, surface roughness. The results of ANOVA are shown in **Table (4.1**). ANOVA is carried out by comparing the F- test value of the parameter with standard F table value (F0.05) at 5% significance level (95% confidence level) if P-values in the table is less than 0.05 then the corresponding variable is considered as statistically significant

From the **Table 4.3,** it can be calculated that input parameters is significant parameters on surface roughness (as its P value is less than 0.05). Stand-off distance also has the considerable effect on surface roughness as its P value is very close to 0.05 and other parameters have very little influence on surface roughness.

Table 4.1: Analysis of Variance for Surface Roughness

Source	SS	DOF	MS	F-value	p-value Prob> F	
Model	56.94664	14	4.0676	4.90151	0.0026	significant
A-Abrasive flow rate	0.07053	1	0.0705	0.08499	0.07749	
B-Water pressure	0.29141	1	0.2914	0.35115	0.05629	
C-Stand-off distance	2.07501	1	2.0750	2.50040	0.01361	
D-Feed rate	0.0972	1	0.0972	0.11713	0.07373	
Residual	11.61818	14	0.8299			
Lack of Fit	5.60146	10	0.5601	0.37239	0.9065	not significant
Pure Error	6.01672	4	1.5042			
Cor Total	68.5648	28				

DOF = **Table 4.1** Analysis of variance for surface roughness

Where,

SS = sum of square

MS = mean sum of square

F=Fisher's ratio

P=Probability of significance

R-Squared = 0.831

Adj R-Squared = 0.661

Pred R-Squared = 0.392

Adeq Precision = 7.211

Values of "Prob> F" less than 0.0500 indicate model terms are significant. Values greater than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 0.37 implies the Lack of Fit is not significant relative to the pure error. There is a 90.65% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit. The "Pred R-Squared" of 0.3923 is not as close to the "Adj R-Squared" of 0.6611 as one might normally expect. This may indicate a large block effect or a possible problem with our model and/or data. Things to consider are model reduction, response transformation, outliers, etc. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 7.211 indicates an adequate signal. This model can be used to navigate the design space.

4.1.3: Results of Surface Roughness Corresponding to BBD

Surface Roughness (Ra)

The Results found from measurement of surface roughness are shown in Table 4.1. From the results of surface roughness measurement, it is found that Ra ranges from 1.53 µm to 5.99 µm. The minimum value of surface roughness is obtained for experiment no.26 at factor setting Abrasive flow rate 400g/min, water pressure 3600bar, stand-off distance 1.5mm, cutting speed 300mm/min. Maximum surface roughness found for experiment no.20 at parametric setting Abrasive flow rate 400g/min, water pressure 3400bar, stand-off distance 1.5mm, cutting speed 250mm/min.

Table 4.2: Results of Surface Roughness Measurement of the Holes as per Box-Behnken Design Matrix

Run	Abrasive Flow Rate g/min	Water Pressure bar	Stand-off Distance mm	Cutting Speed mm/min	Surface Roughness µm
1	400	3600	1.5	300	4.63
2	600	3600	2	300	3.09
3	400	3600	2	350	5.82
4	400	3600	2	250	4.63
5	400	3600	1	250	5.64
6	400	3400	2	300	1.97
7	600	3600	1	300	5.88
8	400	3600	1	350	5.44
9	600	3600	1.5	250	5.6
10	200	3400	1.5	300	2.97
11	600	3400	1.5	300	2.33
12	400	3800	1.5	350	6.1
13	200	3600	1	300	4.75
14	400	3600	1.5	300	1.99
15	400	3800	2	300	5.48
16	200	3800	1.5	300	2.31
17	200	3600	2	300	3.86
18	400	3800	1.5	250	2.61
19	400	3400	1	300	5.8
20	400	3400	1.5	250	5.99
21	400	3600	1.5	300	2.33
22	400	3800	1	300	2.33
23	200	3600	1.5	250	5.64
24	200	3600	1.5	350	4.32
25	400	3600	1.5	300	2
26	400	3600	1.5	300	1.53
27	600	3800	1.5	300	2.7
28	600	3600	1.5	350	5.17
29	400	3400	1.5	350	4.34

4.1.4. Effect of Process Parameters on Surface Roughness (Ra)

To study the effects of process parameters on surface roughness, main effect plots have been drawn by using data in **Table 4.2**.

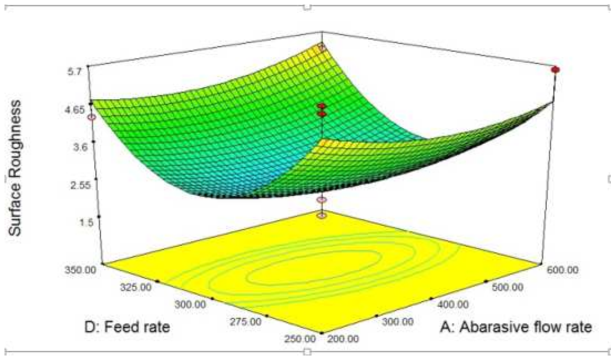

Figure 4.1: Main Effect Plots for Surface Roughness

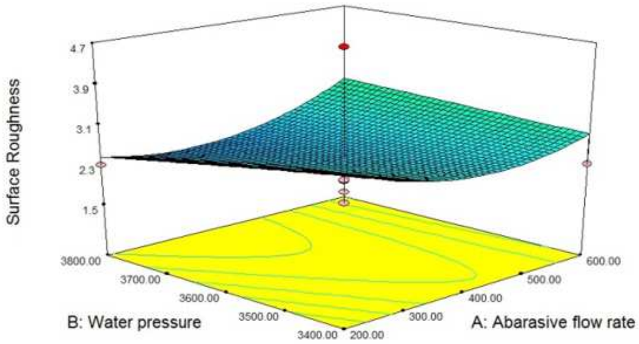

Figure 4.2: Main Effect Plots for Surface Roughness

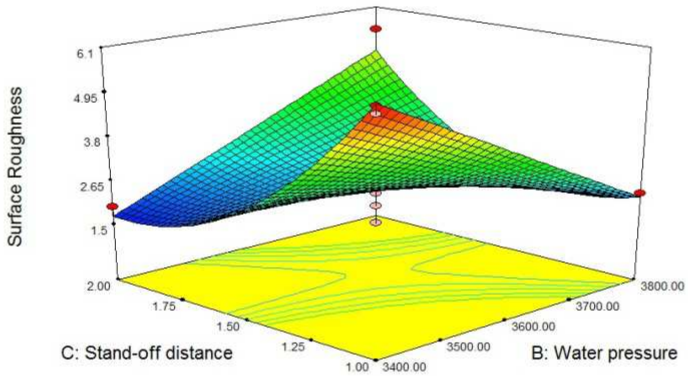

Figure 4.3: Main Effect Plots for Surface Roughness

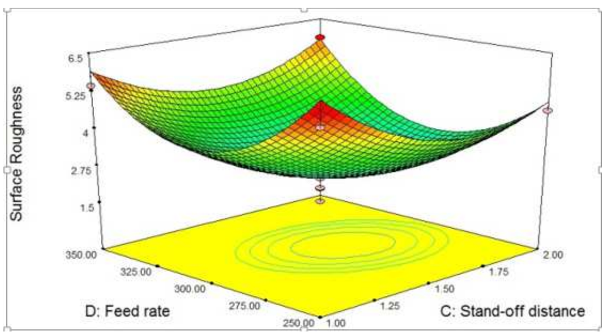

Figure 4.4: Main Effect Plots for Surface Roughness

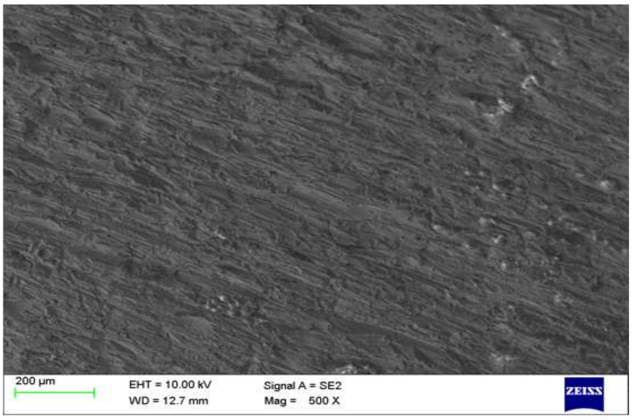

Figure 4.5: SEM Image of AL Alloy 7075 at 500x Magnification

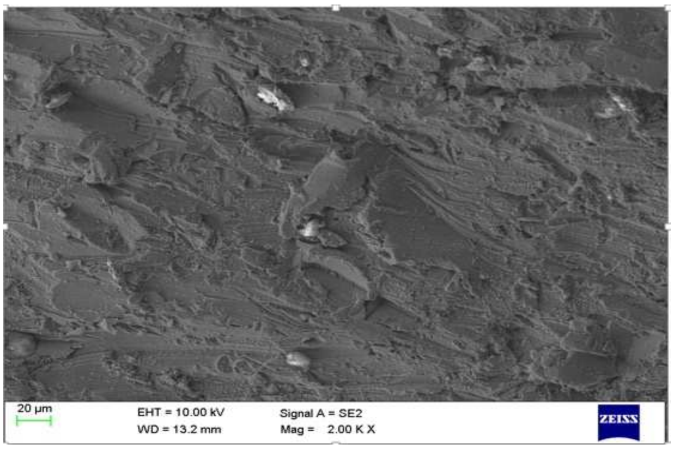

Figure 4.6: SEM Image of Al Alloy 7075 at 2000x Magnification

4.3: Confirmation Test

Once the optimum level of the machining parameters is selected, the final step is to verify the improvement of the quality characteristics using the optimum level of machining parameters. A confirmatory experiment is conducted at optimum combination i.e., Abrasive flow rate 477.31g/min, water pressure 3403.3bar, stand-off distance 1.99mm, feed rate 311.26mm/min from the confirmatory result, it is found that the optimized parametric combination produced surface roughness = 1.494 µm.

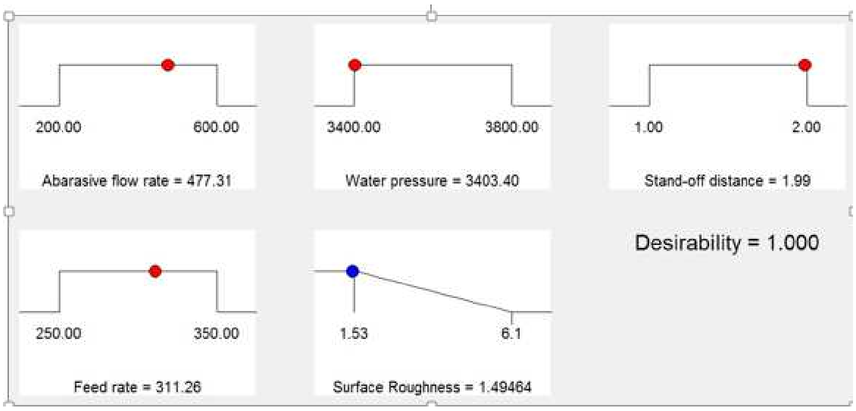

Figure 4.7: AMP Function of Desirability Approach

CONCLUSIONS

Experimental investigations have been carried for the surface roughness in abrasive water jet cutting of 7075 Aluminium alloy. The effects of abrasive flow rate, water pressure, standoff distance and feed rate on surface roughness have been studied. From the experimental results, an empirical model for the prediction of surface roughness in AWJC process of 7075 Aluminium alloy has been developed using regression analysis. The developed model is finally assessed using the experimental data and found to be able to give adequate predictions within the experimental range considered in this study. The effect of water pressure on the surface roughness is more effective after standoff distance.

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